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Carbon Footprint of Milk Processing: A Life Cycle based Approach

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ABSTRACT

This study was undertaken with the aim to assess and enumerate direct and indirect CO_2 emissions from Student Training Dairy Plant, WSDT, using an LCA approach. One litre of milk was chosen to be the functional unit and the operations from milk reception to packaging were considered to be the system boundary for the research. The activity level for Life Cycle Inventory was collected by consulting the personnel at the plant and the data registries available at the plant and the emission factors for the various sources were taken from various international registries such as IPCC and NDRC. The results showed that the indirect emissions contributed the most to the overall carbon emissions, i.e., 19.675 $KgCO_2e$. The LCIA showed the Global Warming Potential of Indirect emissions to be higher than direct emissions.

Key words: *Carbon Footprint, Emissions, Milk, LCA, BOD, COD*

Introduction

Global climate change has emerged as a global dilemma caused by the release of greenhouse gases (GHGs), posing risks to the well-being and safety of human beings and the natural environment (Pringle *et al.,* 2015). Within the realm of GHG emissions, agriculture plays a significant role, accounting for 15 to 25% of total anthropogenic GHG emissions, with dairy products contributing around 5% (Laratte *et al.,* 2014; Hawkins *et al.,* 2015). As the concept of "green consumerism" gains influence in the market, the food industry recognizes the necessity of developing low-carbon food to both reduce their GHG emissions and pursue long-term commercial success (Beske *et al.,* 2014; Biggs *et al.,* 2015).

The GHG Protocol provides definitions for direct and indirect emissions

Direct GHG emissions are emissions originating from sources owned or controlled by the reporting entity. Indirect GHG emissions are emissions resulting from the activities of the reporting entity but occurring at sources owned or controlled by another entity.

Furthermore, the GHG Protocol classifies these direct and indirect emissions into three main scopes:

Scope 1 encompasses all direct GHG emissions.

Scope 2 includes indirect GHG emissions arising from the consumption of purchased electricity, heat, or steam.

Scope 3 comprises other indirect emissions, such as those stemming from the extraction and production of purchased materials and fuels, transport-re-

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([1]Assistant Professor, [2,3]Associate Professor) lated activities involving vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g., transmission and distribution losses) not covered under Scope 2, outsourced activities, and waste disposal, among others.

Life Cycle Assessment (LCA) is characterized as a method for appraising the environmental impacts linked to a product, process, or activity. It achieves this by recognizing and quantifying the energy and resources utilized and the waste discharged into the environment. Moreover, LCA aims to assess the consequences of these energy and resource inputs and identify potential areas for environmental enhancements.

The carbon footprint is a valuable measure that represents the concept of low-carbon practices. It refers to the complete amount of carbon emissions associated with a specific product or service throughout its entire life cycle (Dong *et al.,* 2014).

Optimized utilization of energy has gained international significance as it is considered the most crucial factor for economic progress (Katre and Murari, 2007). Within the dairy and other food processing sectors, the outdated technology employed in the processing, manufacturing, and storage of various products leads to a substantial energy consumption (Janzekovic, 2009; Charan and Prasad, 1993). In dairy plants, energy usage directly pertains to the generation and consumption of utilities such as steam, refrigeration, electricity, and water. Water and steam serve as essential heat transfer media in dairy operations, with water consumption being particularly high in the majority of dairy processes. In their study, Zhao *et al.,* (2017) conducted a simplified assessment based on the product life cycle to determine the carbon footprint associated with a specific locally branded pure milk product. This assessment encompassed various stages, including the production of raw milk, dairy processing, transportation of the milk product, and the disposal of packaging waste.

The global issue of environmental pollution arising from dairy waste is a matter of great concern (Kolhe *et al.,* 2009). Consequently, the expansion of dairy operations has prompted the introduction of new legislation and regulations regarding the management and disposal of manure. With the increasing recognition of the significance of enhanced wastewater treatment standards, the demands placed on the process have become more rigorous (Cristian, 2010). Additionally, the Indian government has implemented stringent rules and regulations pertaining to effluent discharge in order to safeguard the environment.

Therefore, this study was undertaken with the aim to assess the various sources of emissions from and the physico-chemical characteristics of the effluent at a Student Training Dairy Plant.

Materials and Methods

Functional Unit and Description of System Boundary

The choice of the functional unit (FU) has a significant impact on the outcomes, as emphasized by do Boer (2003), and its selection depends on the objective of the study. In the case of milk at the farm gate, the commonly adopted FUs are energy or fat and protein corrected milk (Basset-Mens, 2008; de Vries and de Boer, 2010; Flysjö *et al.,* 2011). For this particular research, the functional unit was defined as 1 Kg Fat and Protein corrected milk, equivalent to 1 litre of packaged milk processed at a Student Training Dairy Plant. Regarding the system boundary, all activities from the milk reception to its packaging at the Student Training Dairy Plant were taken into account. Figure 1 illustrates the system boundary diagram, where the dark black rectangle represents the dairy plant specifically considered for this research.

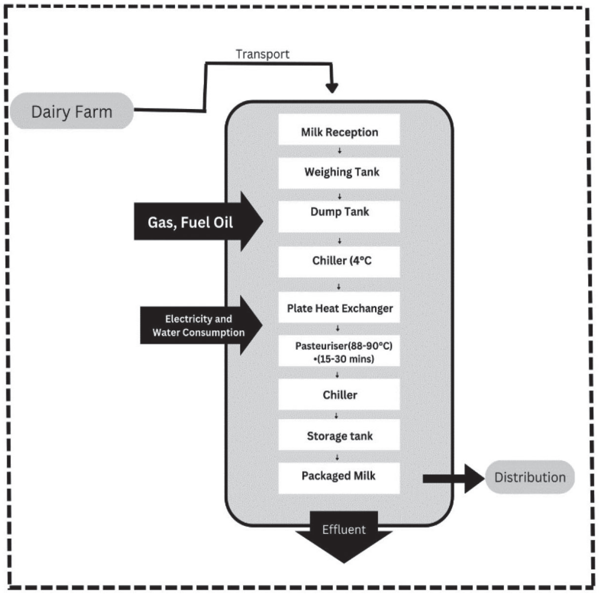

Fig. 1. System Boundary Diagram

Data Collection and Effluent Sample collection

Data collection to determine the activity levels for both direct and indirect emissions was carried out by consulting the staff members working at the Student Training Dairy Plant. The methodology outlined by the Intergovernmental Panel on Climate Change (IPCC, 2006) was followed during this data collection process. The primary focus was placed on the key category of Global Warming. Effluent samples were obtained from a discharge point within the Student Training Dairy Plant. These samples were collected in clean plastic containers and subsequently stored at a temperature of 4°C until they were utilized for analysis. The sampling process took place during the evening.

Direct emissions and Indirect emissions

Direct GHG emissions are emissions from sources that are owned or controlled by the reporting entity. For this study the direct emissions considered were gas and diesel consumed for processing of 1L by milk from Student Training Dairy Plant. The direct emissions were calculated by the methodology shown in Fig. 2.

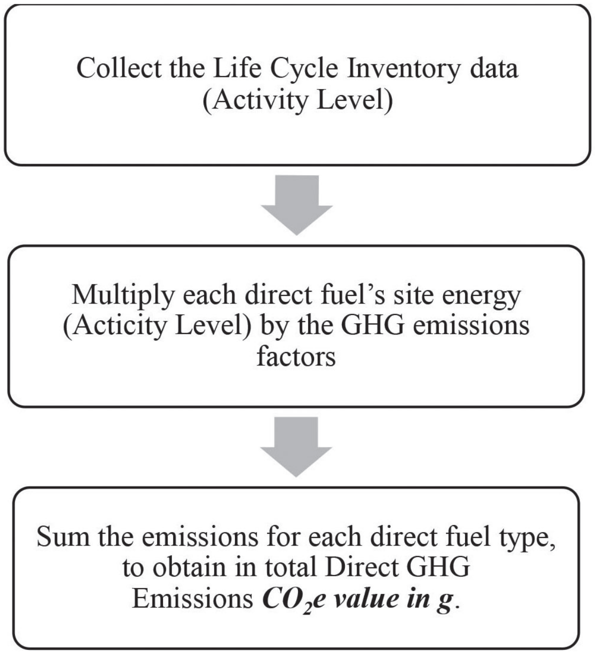

Fig. 2. Direct emissions

The total indirect emissions were calculated using following equation (IPCC, 2006)

GHG direct = $\Sigma_{i=1}^{n} Di \times GWPi$

Where,
i = i^{th} emission source of milk life cycle
D = activity level
GWP = Global Warming Potential

Indirect GHG emissions are emissions that are a consequence of the activities of the reporting entity, but occur at sources owned or controlled by another entity. These emissions for this study were considered to be electricity and water consumption to produce 1L of processed milk at Student Training Dairy Plant. Calculation of the emissions was done according to methodology in Fig. 3.

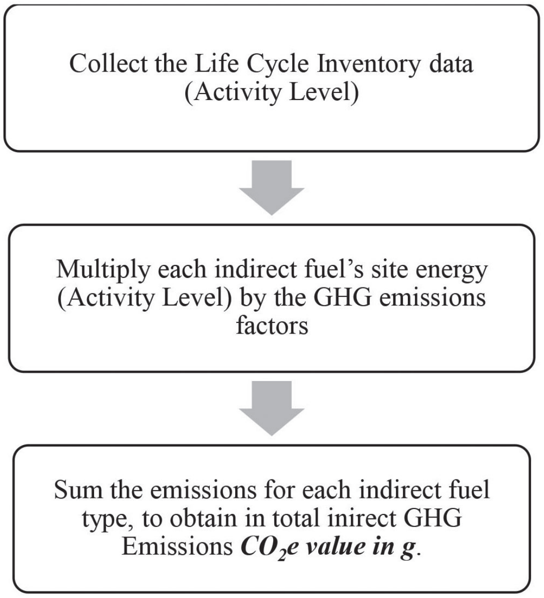

Fig. 3. Indirect Emissions

The total indirect emissions were calculated using following equation (IPCC, 2006)

GHG direct = $\Sigma_{i=1}^{n} Ai \times Ei$

Where,
i = i^{th} emission source of milk life cycle

A = activity level, which involved the amount of all resource and energy during the product life cycle (material input and output, energy use, transportation distance, etc.)

E = GHG emission factor, which referred to the GHG produced per unit activity level, derived from life cycle databases and industrial reports.

Physicochemical Properties of the Dairy Effluent

The effluent samples were analysed for colour, odour, pH, Total Suspended Solids (TSS), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The methods followed for the analysis of pH, TSS, BOD and COD were according to the APHA (1998). The colour and odour of the samples were judged by naked eye and sniffing respectively.

Results and Discussion

Direct emissions during milk processing

In this study, the sources of direct emissions are Diesel and gas only. In order to calculate direct emissions during milk processing the activity level data was taken at Student Training Dairy Plant. Table 1 shows the inventory data for direct emissions during the processing of milk, which are obtained by analogy to Hospido *et al.,* (2003) on Milk LCA.

At the Student Training Dairy Plant, the primary use of fuels is for pre-heating and heating the equipment. The emission factor for Diesel fuel was obtained from the IPCC report (2006), while the emission factor for Gas was sourced from the Federal Register (2010) EPA. Following the IPCC (2006) method, the carbon footprint was determined by multiplying the activity level of each emission source by its respective emission factor. According to the calculations, the carbon footprint values were found to be 10.11 kg for Diesel and 0.7216 kg for Gas, as shown in Figure 4.1. In comparison, Zhao *et al.,* (2017) reported a carbon footprint value of 0.228 kg for tetra pack milk in China. The difference between the results of the present study and those of Zhao *et al.,* (2017) could be attributed to the exclusion of an Ultra High Temperature (UHT) unit within the considered system boundary for the present study. Consequently, the total direct emissions amounted to 0.7315 kg CO_2e. The results are presented in Figure 4.

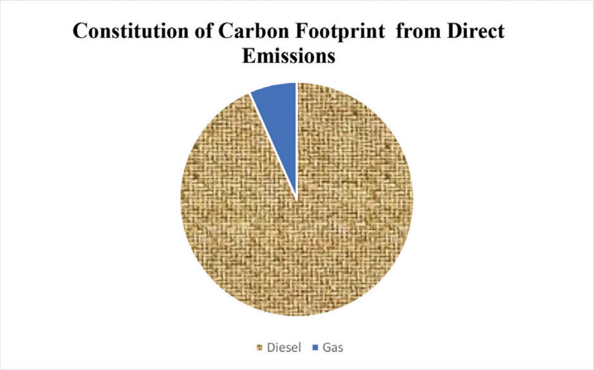

Fig. 4. Direct Emissions

Indirect emissions

Different sources indirect emissions identified in the present system boundary are electricity and water. In order to calculate direct emissions during milk processing the activity level data was taken at Student Training Dairy Plant. Table 2 shows the inventory data for indirect emissions during the processing of milk, which are obtained by analogy to Hospido *et al.,* (2003) on Milk LCA.

Electricity primarily serves the purpose of operating equipment at the Student Training Dairy Plant. The electricity emission factor used in this study is based on the 2014 Baseline Emission Factors for Regional Power Grids in China, which were released by the National Development and Reform Commission (NDRC). Specifically, the emission factor for the Central China power grid was applied. According to Zhao *et al.,* (2013), the conversion resulted in a power grid emission factor of 0.723 kg/kWh. The carbon footprint (CF) values for electricity and wa-

Table 1. Life cycle inventory for direct emissions

Emissions Source	Activity Level	CO_2 Emissions factor	Source of emissions factor	Carbon Footprint ($KgCO_2e$)
Diesel	0.13698kg	73.84 kg/l	Federal Register (2010) EPA	10.11
Gas	0.0136kg	53.06 kg	Federal Register (2010) EPA	0.7216
Total Direct Emissions			10.7315	

Table 2. Life Cycle inventory for indirect emissions

Emissions Source	Activity Level	CO_2 emissions factor	Source of emissions factor	Carbon Footprint ($KgCO_2e$)
Electricity	2.1508 KWh	0.723 kg/KWh	NDRC (2014)	1.5502
Water	0.25 L	66.3 kg/L	Federal Register (2010) EPA	18.12
		Total Indirect Emissions		19.675

ter within the system boundary were determined to be 1.5502 Kg and 18.12 kg, respectively. In comparison, Zhao *et al.*, (2013) calculated CF values of 0.033 kg and 0.0025 kg for tetra pack milk. The disparity between the present study and Zhao *et al.*, (2013) can be attributed to the absence of an Effluent Treatment Plant in the Student Training Dairy Plant, resulting in higher consumption in the current research plant. Consequently, the total indirect emissions accounted for 19.675 kgCO2e. The results are presented in Figure 5.

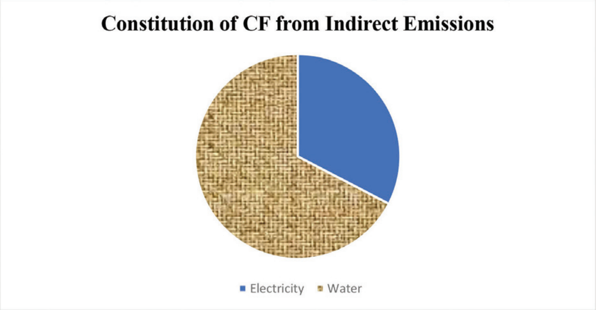

Fig. 5. Indirect Emissions

The overall carbon footprint of the present system boundary is shown in Figure 6.

Physicochemical analysis of the dairy effluent

The dairy effluent samples were analysed for physicochemical properties viz, Colour, Odour, pH, Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and the results are presented in Table 3.

The average total suspended solids (TSS) value observed in this study was 98 mg/L, which aligns with the findings of Chavda and Rana (2014) for dairy wastewater.

The dairy effluent examined in the present investigation exhibited a milky and greyish-black color, accompanied by an unpleasant pungent odor. These characteristics may be attributed to the decomposition of organic matter or the presence of various aromatic and volatile organic compounds (Singh *et al.*, 1998).

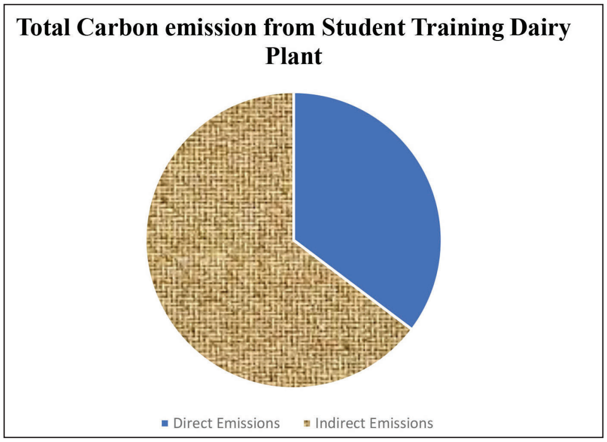

Fig. 6. Overall Carbon Footprint

The average pH of the dairy effluent was determined to be 6. A critical requirement for the biological treatment of dairy wastewater is maintaining a pH value between 6 and 9, as stated by the Water Environment Federation (2007). Effluents from milk and butter factories typically exhibit an active reaction close to neutral, with pH values ranging from 6.8 to 7.4. However, in plants where whey is discharged, the pH of the effluent tends to decrease below 6.2.

Regarding the wastewater's organic content, the average biological oxygen demand (BOD) and chemical oxygen demand (COD) were found to be 30 mg/l and 130 mg/l, respectively. Due to the high organic content in dairy wastewater, primarily consisting of rapidly assimilable carbohydrates, slowly degradable proteins, and lipids, it is characterized by elevated BOD and COD values, ranging from 0.1 to 100 g/l, as observed in studies by Karagdag *et al.*, (2015), Demirel *et al.*, (2004), Venetsaneas *et al.*, (2009), and Kotoupas *et al.*, (2007).

Table 3. Physicochemical properties of Dairy effluent

Parameter	Sample 1	Sample 2	Sample 3
Colour	Light white	Greyish White	Greyish White
Total Suspended Solids (mg/l)	100	98	98
pH	6.3	5.8	6.0
Odour	Pungent	Pungent	Pungent
BOD (mg/l)	24	32	28
COD (mg/l)	136	130	124

Life Cycle Impact Assessment

This was the final phase of LCA in which impact category was selected and analysed with respect to the Life Cycle inventory data. In present study, Global Warming is the only impact category taken into consideration. According to the definition, carbon dioxide (CO_2) has a Global Warming Potential (GWP) of 1, regardless of the chosen time period, as it serves as the reference gas. CO_2 has a long-lasting presence in the climate system, with its emissions leading to atmospheric concentration increases that can persist for thousands of years, as stated by the United States Environmental Protection Agency. Figure 6 presents the Global Warming Potential in kgCO2e for the specific emission sources considered at the Student Training Dairy Plant.

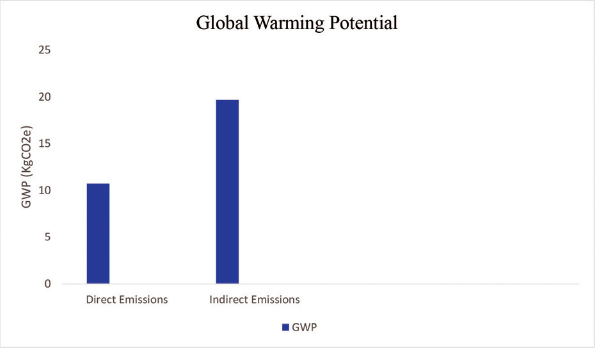

Fig. 6. Global Warming Potential

Conclusion

The study found out that the sources having the highest carbon footprint were indirect sources of emissions at the plant having a CF of 19.675 kgCO2e whereas the direct sources had comparably low CF of 10.7315 kgCO2e. The physicochemical properties of the dairy effluent were also studied. The Biological Oxygen Demand of the effluent was found to be moderate whereas the Chemical Oxygen Demand of the effluent was comparatively higher than the Biological Oxygen Demand. Installation of an Effluent Treatment Plant at the system boundary site would be helpful to treat the effluent before discharge. Currently, enterprises have the option to voluntarily engage in carbon foot printing as they consider taking on additional social responsibilities to enhance the environmental performance of their products However, there may be concerns about the added costs associated with conducting a comprehensive carbon footprint assessment, which could create uncertainty regarding commercial success. Consequently, it is crucial for governments to play a leading role in promoting sustainability by incentivizing green innovation among enterprises through well-designed policy instruments. This approach can help businesses achieve a mutually beneficial outcome, where both the environment and the economy thrive.

References

APHA, 1998. Standards methods for the examination of water and waste water. American Public Health Association, 19th edition, 1015 Fifteenth Street N.W. pp. (1-1)-10-1

Basset-Mens, Kelliher, Ledgard, Cox. 2008. Uncertainty of global warming potential for milk production on a New Zealand farm and implications for decision making. *Int. J. Life Cycle Assess*., 14 (2009): 630-638

Beske, L. and Seuring, 2014. Sustainable supply chain management practices and dynamic capabilities in the food industry: A critical analysis of the literature. *International Journal of Production Economics*, C (152): 131-143

Biggs, Schluter, Schoon, 2015. Principles for building resilience: Sustaining ecosystem services in social-ecological systems

Charan and Prasad, 1993. Energy Conservation in milk spray-drying plant. *Journal of Food Engineering*, 18(3): 247-258

Pratiksinh Chavda and Apurva Rana 2014. Performance evaluation of Effluent Treatment Plant of Dairy Industry. *Int. Journal of Engineering Research and Applications.* 9(3): 37-40

Christian, 2010. Characteristics of Untreated Wastewater produced by Food Industry. *University of Oradea Publishing House*. ISSN: 1224-6255

De boer, 2003. Environmental impact assessment of conventional and organic milk production. *Livestock Production Science*. 80(1-2): 69-77

Demirel, Yenigun, Onay, 2004. Anaerobic treatment of dairy wastewaters: a review. *Process Biochem*. 40(25): 83–95.

De Vries and de Boer, 2010. Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livestock Science*. 128(1-3): 1-11

Dong, Xia, Chen, 2014. Carbon Footprint of Urban Areas: An Analysis Based on Emission Sources Account Model. *Environmental Science & Policy*. 44(2014): 181-189

EPA, 2017. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015. EPA 430-P-17–001. Environmental Protection Agency (EPA), Washington DC.

Flysjö, Henrikkson, Cederberg, Ledgard and Englund

2011. The impact of various parameters on the carbon footprint of milk production in New Zealand and Sweden. *Agricultural Systems*. 104(6): 459-469.

Francisco A. Riera, Adrian Suarez and Claudia Muro, 2013. Nanofiltration of UHT flash cooler condensates from a dairy factory: Characterisation and water reuse potential. *Desalination*. 309(2013): 52-63.

Hawkins, Bacher, Essl, E. Hulme, M. Jeschke, Kuhn, Kumschick, Nentwig, Pergl, Pysek, Rabitsch, Richardson, Vila, Wilson, Genovesa and Blackburn, 2015. Framework and guidelines for implementing the proposed IUCN.

Hospido, Moreira and Feijoo, 2003. Simplified life cycle assessment of Galician milk production. *International Dairy Journal*. 13(10): 783-796.

Intergovernmental Panel on Climate Change – IPCC. 2006. Guidelines for national greenhouse gas inventories. Geneva.

Janzekovic, 2009. Energy saving in milk processing. *Journal of Achievements in Materials and Manufacturing Engineering*. 33(2): 197-203

Karadag, Körolu, Ozkaya and Cakmakci, 2015. A review on anaerobic biofilm reactors for the treatment of dairy industry wastewater. *Process Biochem*. 50(2): 62–71.

Katre and Murari 2007. Product technology: A crucial aspect of effective energy management. *Beverage and food World*, April edition, 43-45.

Kolhe, A.S., Ingale, S.R. and Bhole, R.V. 2009. Effluents of Diary Technology. *Int. Res. Jr. Sodh,Samiksha* and *Mulyankan*. 5 (II): 459-4.

Kotoupas, Rigas and Chalaris, 2007. Computer-aided process design, economic evaluation and environmental impact assessment for treatment of cheese whey wastewater. *Desalination*. 213(1-3): 238–252.

Laratte, Guillaume, Kim and Birregah, 2014. Modeling cumulative effects in life cycle assessment: The case of fertilizer in wheat production contributing to the global warming potential. *Science of the Total Environment*. 481: 588-595.

National Development and Reform Commission – NDRC. 2014. China regional power grid emission factor report. Dublin: NDRC.

Pringle, Visconti, Di Marco, G. Martin and Rondinini, R. Rhodes, 2015. Climate change modifies risk of global biodiversity loss due to land-cover change. *Biological Conservation*. 187(2015): 103-111.

Rui Zhao, Yao Xu, Xiangyu Wen, Ning Zhang, Jiapei CAI, 2017. Carbon footprint assessment for a local branded pure milk product: a lifecycle-based approach. *Food Science & Technology*. 38(1): 98-105.

Singh, Varshneya and Nagarkoti, 1998. Assessment of physico-chemical parameters of effluents of three factories of Bareilly district and their possible effects on grazing animals and cereals. *J. Environ. Biol*. 19(3): 271-274.

Venetsaneas, Antonopoulou, Stamatelatou, Kornaros and Lyberatos, 2009. Using cheese whey for hydrogen and methane generation in a two-stage continuous process with alternative pH controlling approaches. *Bioresour Technol*. 100(15): 3713–3717.

Water Environment Federation. Temperature. Chapter 17. Characterization and sampling of wastewater. In: Operation of municipal wastewater treatment plants, no. 11. New York, NY, USA: WEF Press; 2007. p. 5.

Zhao, R., Neighbour, G., McGuire, M. and Deutz, P. 2013. A software based simulation for cleaner production: a game between manufacturers and government. *Journal of Loss Prevention in the Process Industries.* 26(1): 59-67. http://dx.doi.org/10.1016/j.jlp.2012.09.006